HYD 539

HYD 539

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF GRANBY DAM
SPILLWAY MODIFICATION
COLORADO-BIG THOMPSON PROJECT, COLORADO

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Report No. Hyd-539

Hydraulics Branch
DIVISION OF RESERACH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

May 1965

HYD 539

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ABSTRACT

Hydraulic model studies of the proposed Granby Dam spillway modification indicated that the preliminary design of the modification was satisfactory with the addition of a plunge basin not originally contemplated. Operation of the existing spillway at a maximum rate of 1,168 cfs eroded the mountainside and undermined the end of the chute. The modifications proposed include removal of the downstream 160 ft of spillway and construction of a new chute with flip bucket and riprap-lined plunge basin downstream. The model studies were undertaken to develop the hydraulic design of these features. A flow deflector pad on the chute floor and a transition for the curved superelevated portion of the chute was developed to provide more nearly symmetrical flow distribution in the flip bucket jet. Increasing the tangent angle at the lip of the flip bucket to 45 deg and lowering the elevation of the basin floor at the bucket lip increased the effectiveness of the plunge basin pool. The basin was developed to still the energy in flows up to 3,000 cfs and to prevent erosion in the area adjacent to the flip bucket for flows up to 12,000 cfs. Pressures recorded in the flip bucket indicated satisfactory pressure conditions would occur at the entrance to the left wall drain and on the downstream face of the lip and that the training walls should be designed to withstand a pressure of about 60 ft of water at the invert of the bucket radius.

DESCRIPTORS--*spillways/ *chutes/ *flip buckets/ roughness coefficients/ hydraulic models/ research and development/ model tests/ laboratory tests/ cavitation/ negative pressures/ erosion/ hydraulic similitude/ riprap/ flow control/ energy dissipation/ hydraulics/ jets/ hydraulic structures/ discharge measurement/ water pressures/ open channel flow/ erosion control/ discharges/ channels/

IDENTIFIERS--subatmospheric pressures/ Colorado-Big Thompson Project/ flow deflectors/ Colorado/ hydraulic design/ design modifications/ plunge basins

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of Chief Engineer
Division of Research
Hydraulics Branch
Structures and Equipment Section
Denver, Colorado
May 1965

Report No. Hyd-539
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Subject: Hydraulic model studies of Granby Dam Spillway Modification--Colorado-Big Thompson Project, Colorado

PURPOSE

The studies were conducted to develop the hydraulic design of the proposed spillway modification including the chute, flip bucket, and plunge basin.

RESULTS

1. Except for the addition of a plunge basin not originally contemplated, the general concept of the preliminary design was satisfactory.

2. A riprap-lined plunge basin (Figure 2) satisfactorily dissipated the energy of flows up to 3,000 cfs (cubic feet per second), and prevented erosion at the flip bucket for flows up to the maximum design discharge of 12,000 cfs.

3. A flow-deflector pad on the spillway chute floor in conjunction with a transition from the existing portion of the chute (Figure 4) provided good flow distribution in the flip bucket.

4. A flip bucket with a 45° lift directed the jet steeply into the plunge basin pool and prevented excessive drawdown in the pool water surface and, thereby provided maximum energy dissipating efficiency.

5. Pressures recorded in the flip bucket indicated satisfactory pressure conditions would occur at the entrance to the drain in the left wall and on the downstream face of the lip and that the training walls should be designed to withstand a pressure of approximately 60 feet of water at the invert of the bucket radius.

ACKNOWLEDGMENT

The final plans evolved from this study were developed through the cooperation of the staffs of the Dams Branch and the Hydraulics Branch during the period February through July 1964. Laboratory photography was by W. M. Batts, Office Services Branch.

INTRODUCTION

Granby Dam, Colorado-Big Thompson Project, is located about 4 miles northeast of the town of Granby, Colorado (Figure 1). The dam is a combination earth and rock fill structure having a height of 240 feet above the river. It intercepts the flow of the Colorado River, Willow Creek, Meadow Creek, and Strawberry Creek to form a storage reservoir. Water from the reservoir is pumped into Shadow Mountain Lake and, thus, made available for delivery through the Continental Divide Tunnel to the eastern slope of the Divide.

The outlet works and spillway with capacities of 500 cfs and 12,000 cfs, respectively, are located in the left abutment of the dam. The existing spillway chute (Figure 2) is a superelevated, curved channel that conveys the flow from the gate structure to the edge of the mountainside where it discharges into the atmosphere approximately 170 feet above the left bank of the river channel. The spillway operated in the summer of 1962 discharging 17,000 acre-feet of water at a maximum rate of 1,168 cfs. This operation eroded the mountainside and undermined the end of the chute, endangering its stability (Figure 3).

To prevent further undermining of the chute, plans were made to modify the existing spillway. These modifications (Figures 2 and 4) will include removal of the downstream 160 feet of the existing chute, excavation and construction of a new chute with flip bucket, and construction of a riprap-lined plunge basin downstream from the flip bucket on the left bank of the river channel. Model studies for the original spillway design are described in Hydraulic Laboratory Report No. Hyd-109.1/

Dimensions of hydraulic features are listed in Table 1 for both English and metric units.

THE MODEL

The model (Figure 5) was a 1:36 scale reproduction of the spillway including the immediate reservoir area surrounding the intake structure, the outlet works discharge channel, and a reach of river channel extending approximately 600 feet downstream from its junction with the outlet works channel.

The modeled portion of the reservoir area and approach channel was contained in a 14-foot-wide by 11-foot-long head box. A 6-inch rock baffle extended across the width of the box to quiet the reservoir water

1/Hyd-109 "Hydraulic Model Studies of Granby Dam Spillway, Colorado-Big Thompson Project," by R. R. Pomeroy, March 31, 1942.

supply. The floor of the head box was at elevation 8236. The spillway approach channel was molded of concrete while the upstream face of the dam on both sides of the approach channel was constructed of wood.

The spillway crest was molded of concrete screeded to sheet metal templates. The center pier was constructed of wood and the approach sidewalls were of sheet metal. Slide gates made from 1/2-inch brass plate, were installed in place of the radial gates.

Straight portions of the chute were made of wood; the spiral curve and superelevated portions were screeded in concrete; and the vertical curve and flip bucket were fabricated from sheet metal over wooden templates.

The spillway discharge channel between the spillway and the river channel, including the riprap-lined plunge basin was formed in sand, so that erosion studies could be conducted. The outlet works channel and river channel were molded in concrete. Two tailwater staff gages were installed in the river channel, one on the centerline of the spillway and the other near the model tailwater control gate about 300 feet farther downstream. Tailwater elevations were controlled in accordance with the values shown on Figure 6.

THE INVESTIGATION

Scope

The investigation was concerned with flow conditions in the modified chute, flip bucket, and discharge channel for spillway flows up to 12,000 cfs. However, the more frequent smaller flows of 600, 1,200, and 3,000 cfs were of primary concern.

Preliminary Modified Chute

Description.--The preliminary chute (Figure 7) extended on a tangent from the existing spillway chute at Station 4+51. The chute floor transitioned from the superelevated section at Station 4+51 to a level section in a distance of 76.5 feet, and followed a slope of 0.03 to the P.C. of a 76-foot-radius vertical curve. From the P.T. of the vertical curve the chute dropped 150.26 feet on a slope of 0.89 to the invert of the 40-foot-radius flip bucket.

Flow characteristics.--Flow was not uniformly distributed across the width of the preliminary chute. The unsymmetrical flow distribution persisted through the flip bucket. As a result, the right side of the jet carried much farther downstream from the bucket (Figure 8). This asymmetry was more noticeable for discharges up to 3,000 cfs than for the larger flows.

To correct this flow condition, a flow deflector consisting of a raised pad was installed on the chute floor. Many sizes and locations for the flow deflector were tested to obtain the desired results. In addition, shortening the transition from the existing superelevated floor improved the flow distribution. A transition extending from Station 4+51 to Station 4+66.5 was most satisfactory; however, the low side of the superelevated section at Station 4+51 was 6 inches lower than the chute floor at Station 4+66.5 (Figure 7). Thus, a portion of the chute floor did not drain. Therefore, a longer transition was desirable to provide natural drainage.

Recommended Chute

Description.--A 46-foot-long transition terminating at Station 4+97 was adopted for the recommended chute and a flow deflector was installed on the right side of the chute floor between Stations 5+27.50 and 5+79.38, the P.C. of the vertical curve (Figure 9). The transition was 30.5 feet shorter than the preliminary design and provided natural drainage for all parts of the chute floor. The deflector consisted of two faces of a pyramid with the high point 1 foot above normal floor elevation at the right wall of the chute. From the high point the pad sloped downward in three directions: (1) to the centerline of the chute; (2) downstream a distance of 21.38 feet to the P.C. of the vertical curve; and (3) upstream a distance of 30.5 feet to a contraction joint.

Flow characteristics.--Velocities determined from the measured flow depths at Station 8+12.84 for gate-controlled flows were found to approximately represent the theoretical prototype values for a roughness coefficient of $n = 0.013$ in Manning's formula, Figure 10. Gate-controlled flows in the recommended chute (Figure 11) produced fairly uniform jets, particularly for 1,200 cfs (Figure 12). For 3,000 cfs the flow was concentrated slightly to the left of center and for 600 and 12,000 cfs the flow was concentrated slightly to the right. This same distribution was indicated by the flow depth measurements (Figure 10).

The flow distribution could be changed by increasing or decreasing the head on the gates, particularly for the lower flows. When the head was increased, causing higher velocities in the chute, the concentration of the jet moved to the left at 1,200 cfs. When the head was decreased, as with uncontrolled flow, the velocities were less and jet was concentrated to the right of center for flows up to 3,000 cfs. However, these were not anticipated operating conditions and were not tested further.

Preliminary Flip Bucket and Plunge Basin

Description.--The preliminary flip bucket (Figure 7) had a bucket radius of 40 feet and a flip angle of 22.5°. The bucket invert was at elevation 8063.95 and the lip elevation was 8067.00.

Flow characteristics. --The jet from this bucket severely eroded the discharge channel between the flip bucket and the river channel. Therefore, the discharge channel was lined with riprap for a distance of 150 feet downstream from the bucket. The model riprap (Figure 13) consisted of gravel up to 1-1/2 inches in diameter, representing prototype stones up to about 54 inches in diameter.

The model was operated starting with a discharge of 600 cfs and increasing this in increments of 200 cfs to a discharge of 3,000 cfs. Considerable movement of the stones began at 1,800 cfs and at 2,400 cfs the jet eroded a 20-foot-deep hole about 110 feet downstream from the bucket.

The erosion hole formed during this test was used to determine the size of a preliminary plunge basin. The invert of the preliminary basin was 50 feet wide and sloped downward from elevation 8060 at the bucket lip to elevation 8030 in a length of 110 feet and then upward on a 3:1 slope to elevation 8055. The side slopes were 2:1, and the basin was lined with a 6-foot-thick layer of riprap.

The riprap at the downstream end of the preliminary plunge basin was severely eroded by a discharge of 2,400 cfs, indicating that the basin was too short.

Basin and Flip Bucket Modifications

Since it was desired to provide energy dissipation for discharges up to 3,000 cfs the preliminary basin was lengthened 90 feet. The elevation of the floor of the basin at the bucket was lowered 1 foot to elevation 8059. The elevation of the lowest point of the basin, 200 feet downstream from the bucket, was maintained at elevation 8030; the invert of the basin flared from 40 feet wide at the bucket to 100 feet wide in a length of 275 feet. At the same time the bucket radius was reduced to 20 feet and the bucket lip lowered to elevation 8060. The slope of the chute entering the bucket and the tangent angle at the bucket lip were not changed.

The longer basin appeared to be adequate for discharges up to 3,000 cfs. However, at 3,000 cfs the water surface in the pool was drawn down 12 feet below the water surface elevation in the stream channel; this drawdown reduced the effectiveness of the pool. Increasing the flip angle to 45° steepened the angle at which the jet plunged into the pool. This change reduced the drawdown from 12 feet to approximately 6 feet and improved the effectiveness of the pool in dissipating the energy.

Further modifications were made by lowering the invert of the discharge channel at the downstream end of the basin from elevation 8055 to elevation 8050 to reduce the velocity of flow in the channel during spillway operation, and to allow circulation of water from the river to the pool when the spillway was operating, thus reducing the possibility of a stagnant pool in the plunge basin.

The ground water was expected to maintain the pool in the plunge basin at elevation 8050 when neither the spillway nor outlet works were operating. Thus, the upstream end of the basin at elevation 8059 was unsubmerged and subject to erosion by small flows from the bucket. To avoid this, the floor of the basin at the end of the bucket was lowered to elevation 8045. At the same time the sloping chute was lengthened to place the bucket invert at elevation 8045 and the bucket lip 2 feet above pool elevation 8050.

With this bucket arrangement the water surface level in the pool interfered with the undersurface of the jet. This interference caused an undercurrent that pulled the sand at the end of the bucket up through the 6-foot layer of riprap, thus lowering the riprap several feet at the upstream end of the basin. At 3,000 cfs the jet lowered the water surface in the pool to elevation 8045, or 4 feet below the stream elevation as compared to 6 feet with the previous bucket arrangement.

A basin that flared to a maximum width of 200 feet was tested with the bucket lip raised to elevation 8057, and the bucket invert raised to elevation 8051.14. At a discharge of 3,000 cfs the water surface level in the pool was about 1 foot above that which occurred with the 100-foot-wide basin, which was not considered to be a sufficient gain in pool depth to warrant the more costly basin.

Recommended Flip Bucket and Plunge Basin

Description.--In the recommended flip bucket the invert was at elevation 8051.14 on the arc of a 20-foot radius (Figure 3). The lip of the bucket was at elevation 8057, on a 45° angle with the horizontal (Figure 4). The downstream portion of the lip sloped downward on a 10° angle for a distance of 12 inches. In the plunge basin (Figure 2) the invert sloped downward from elevation 8045 at the bucket to elevation 8030, 200 feet downstream. The basin then sloped upward on a 3:1 slope to the discharge channel at elevation 8050. The floor of the basin was 40 feet wide at the bucket and flared uniformly to a width of 100 feet at the discharge channel. The side slopes were 2:1. The side slopes, invert, and end slope were lined with a 6-foot layer of riprap ranging in size up to 36 inches in diameter.

Flow characteristics.--A hydraulic jump formed in the bucket as it first began to discharge. The flow spilled over the bucket lip and dropped vertically downward 7 feet, to the pool. Between 500 and 600 cfs the jet sprang clear of the bucket lip. At 600, 1,200, and 3,000 cfs (Figures 14 and 15) the jet plunged into the basin as designed and the pool adequately dissipated the energy in the jet.

No erosion occurred at 600 and 1,200 cfs. At 3,000 cfs, the erosion in the basin was minor (Figure 16A). Erosion was noticed in the basin floor about 200 feet downstream from the flip bucket after several days of intermittent model operation at flows up to 3,000 cfs.

The 6-foot layer of riprap was eroded to the underlying sand bed; however, the sides and end of the basin remained intact. No erosion occurred in the first 100 feet of basin, indicating that the 6-foot layer of riprap was ample in this region.

The riprapped basin was capable of withstanding flows between 3,000 cfs and 4,500 cfs for short periods. However, considerable damage occurred at the end of the basin when the flow was increased to 6,000 cfs. As the flow was increased to 12,000 cfs (Figures 17 and 18), the point of impact moved farther downstream and eventually was beyond the 3:1 upward slope of the basin. Erosion for these flows was severe (Figure 16B). If these flows should occur in the prototype, maintenance may be required to remove deposits of eroded material that might cause excessive tailwater elevations at the spillway flip bucket and outlet works. Repair of the plunge basin will probably not be required since none of these flows caused any movement of the riprap within approximately 100 feet of the flip bucket. Erosion of the downstream end of the basin would enlarge the plunge basin pool and, thereby, increase its effectiveness. Water surface elevations and jet measurements for various discharges from 600 cfs up to 12,000 cfs are recorded in Figure 22.

It was noted that for flows of 9,000 and 12,000 cfs the water surface elevation in the plunge basin was above the elevation of the bucket lip and interfered with the undersurface of jet. This interference is indicated in Figure 17 by the dark streak across the jet at the bucket lip. The interference caused particles of water to be peeled from the undersurface of the nappe and presented a ragged appearance (Figure 18). After a short period of operation at these high flows the amount of interference was reduced because the pool elevation lowered as the bar of material eroded and moved downstream.

Pressures.--Pressures in the recommended flip bucket were measured to aid in the design of the entrance to a drain in the left wall of bucket near the invert (Figure 4), to aid in the structural design of the walls, and to verify the proper angle for the downstream face of the bucket lip.

Pressures at the drain were positive as indicated by Piezometer 1 (Figure 20). The inside diameter of Piezometer 1 was made geometrically similar to that of the 6-inch drain, so that the drain itself acted as a pressure tap. A piece of No. 18-gage sheet metal was placed along the wall on the upstream side of the drain so that the drain entrance was in effect recessed into the wall. This did not materially lower the pressure from that shown in Figure 20; therefore, it was concluded that no subatmospheric pressures would exist at the drain but that the downstream edge of the recess be tapered on a 1:24 slope to provide a smooth flow surface.

Pressures at the base of the bucket walls were recorded to determine the maximum pressure on the walls. Based upon the pressures previously recorded in other flip buckets,2/ the maximum pressure was expected to occur at the base of the walls approximately six-tenths of the bucket arc length from the P.C. of the bucket curvature. Due to the unsymmetrical flow in the chute, piezometers were installed at the base of both walls at approximately 0.5, 0.6, and 0.75 of the arch length (Figure 20). The flow surfaces around all piezometers were made as smooth as possible before taking the pressure measurements. Piezometer 3 was inadvertently placed on a slight angle away from the flow and a short distance above the base of the wall, which probably accounts for the lower readings at this piezometer.

The maximum pressures were at the base of the right wall. At 12,000 cfs the maximum observed pressure was approximately 60 feet of water or 20 times the flow depth at the bucket invert. It was noted also that the pressure-flow depth ratio increased directly with discharge.

Piezometer 7 was installed on the upstream side of the bucket lip at the centerline, to determine if the angle between the bucket invert and the downstream portion of the bucket lip was sufficient to prevent severe subatmospheric pressures. The floor of the bucket was constructed of sheet metal and bent downward 10° from horizontal to form the bucket lip. This provided a 55° change in direction which is 20° more than the recommended minimum2/ necessary to prevent severely subatmospheric pressures at the end of the bucket. Initial tests showed subatmospheric pressure equivalent to about 20 feet of water to exist on the upstream side of the lip; however, by increasing the sharpness of the break in the sheet metal to more nearly represent the sharpness of the concrete prototype surface, the pressure was increased to 5 feet of water (Figure 20). Therefore, it was concluded that the prototype would provide satisfactory pressures at the lip of the bucket and that there would be no tendency for the underside of the jet to cling to the downstream face of the lip.

2/Paper No. 3236, ASCE Transactions, Volume 126, Part I, 1961, page 1270, "Improved Tunnel-Spillway Flip Buckets," by T. J. Rhone and A. J. Peterka.

Table 1

DIMENSIONS OF HYDRAULIC FEATURES

Feature		
Height of dam	240 feet	73.15 meters
Spillway design capacity	12,000 cfs	339.80 cms
Outlet works capacity	500 cfs	14.16 cms
Spillway discharge (Year 1962)	17,000 acre-feet	20.97×10^6 cubic meters
Rate of discharge (Year 1962)	1,168 cfs	33.07 cms
Spillway drop from end of chute to left bank of stream (Year 1962)	170 feet (approx)	52 meters (approx)
Spillway drop from horizontal chute to flip-bucket invert	200 feet (approx)	61 meters (approx)
Chute width	40 feet	12.19 meters
Flip-bucket radius	20 feet	6.96 meters
Plunge basin length	260 feet	79.25 meters
Maximum depth of basin below bucket lip	27 feet	8.23 meters

FIGURE I
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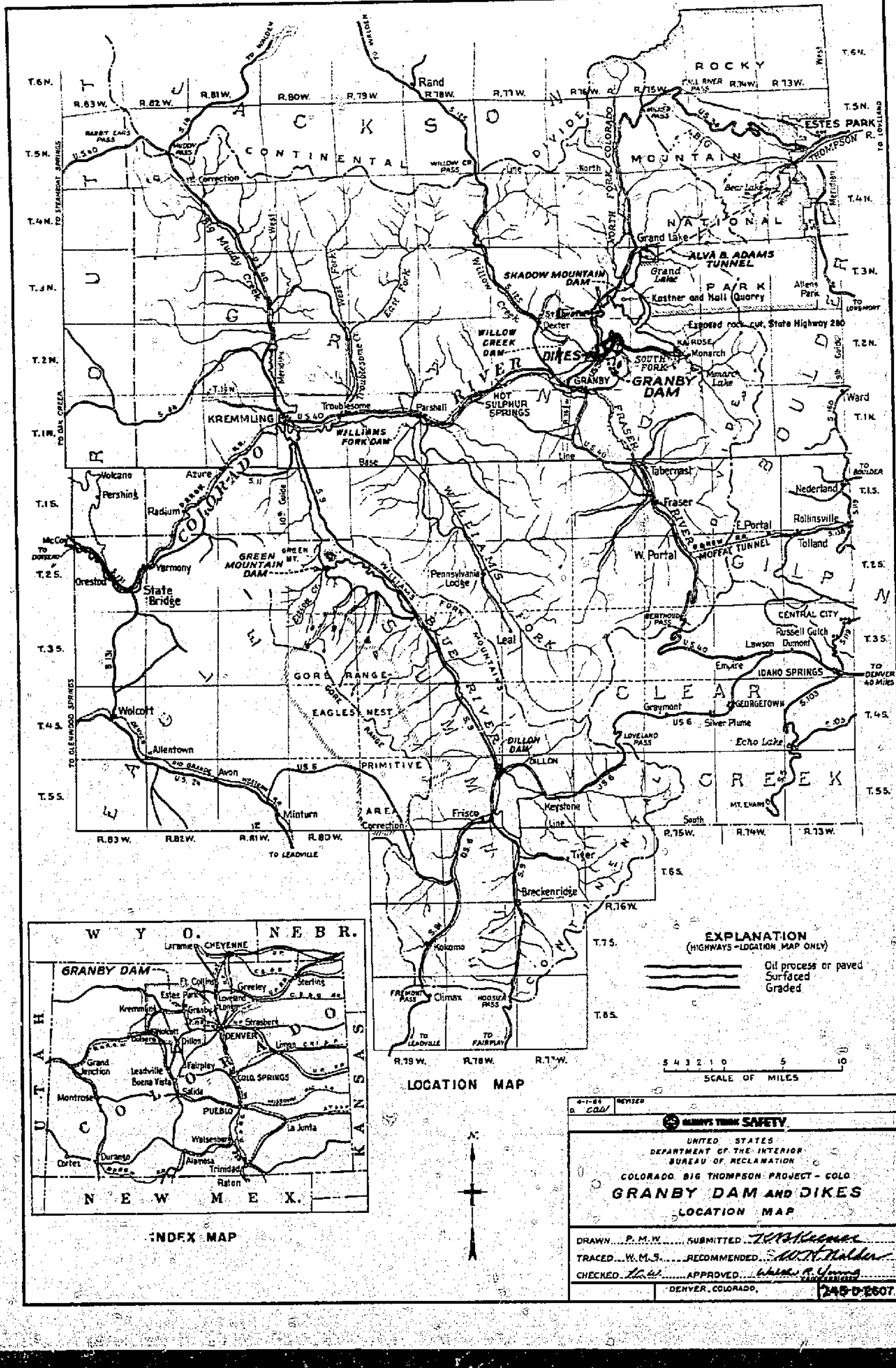

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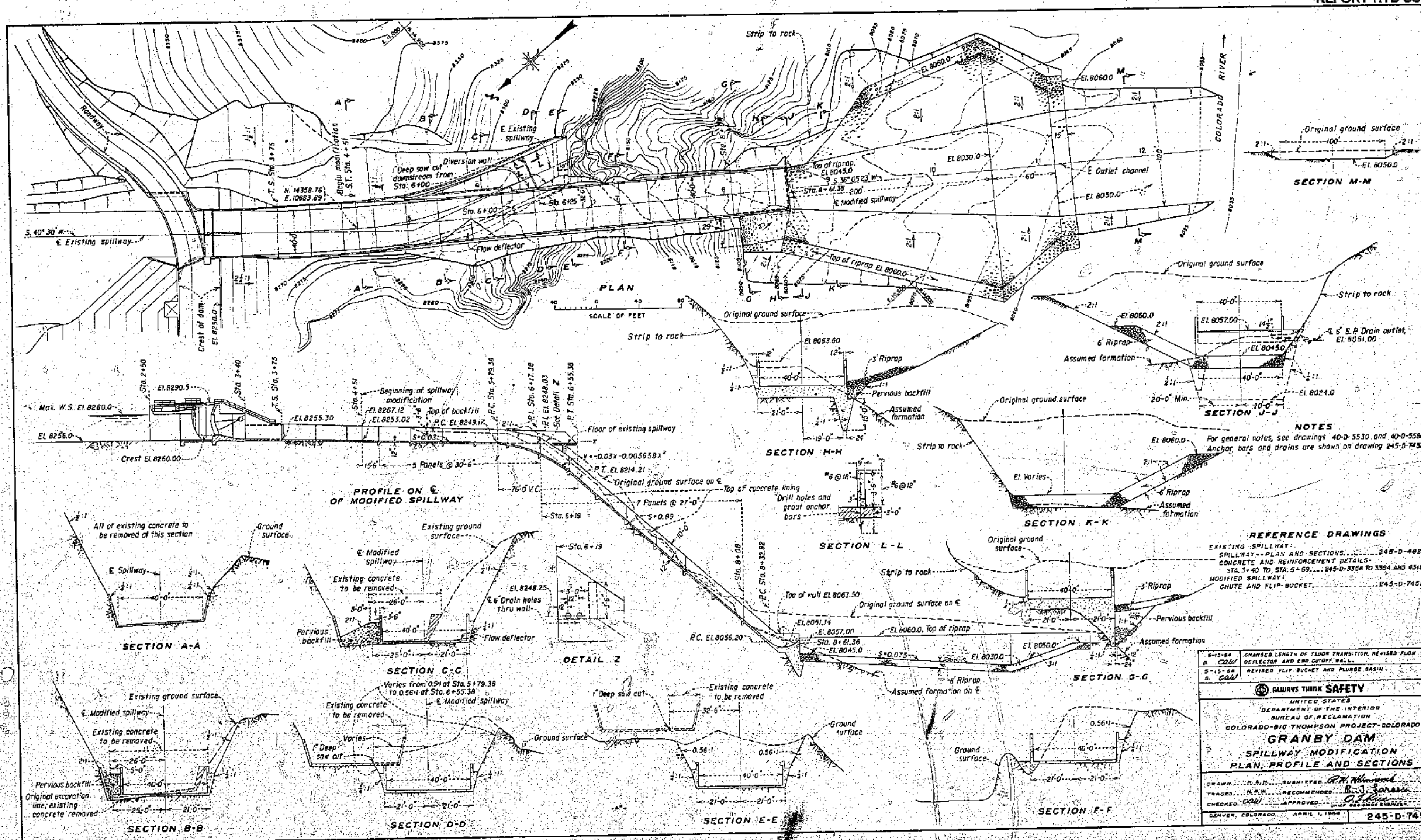
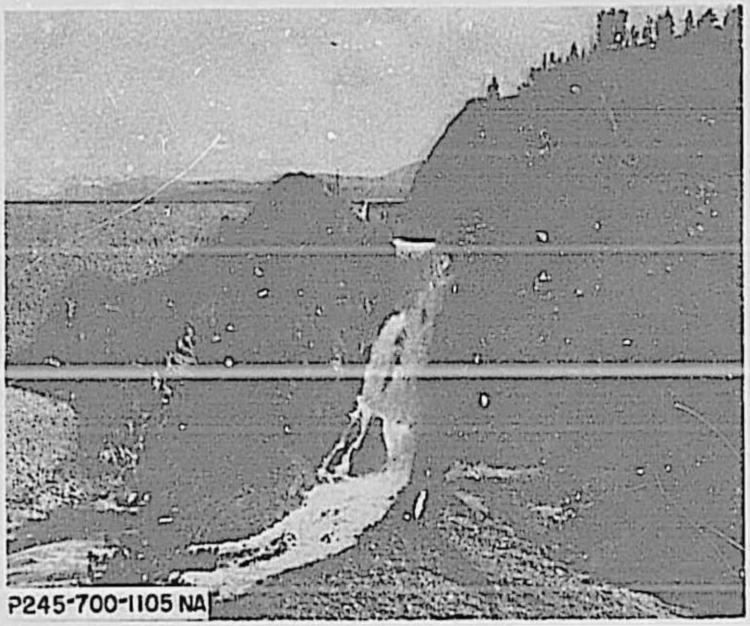
COLORADO BIG THOMPSON PROJECT - COLO.

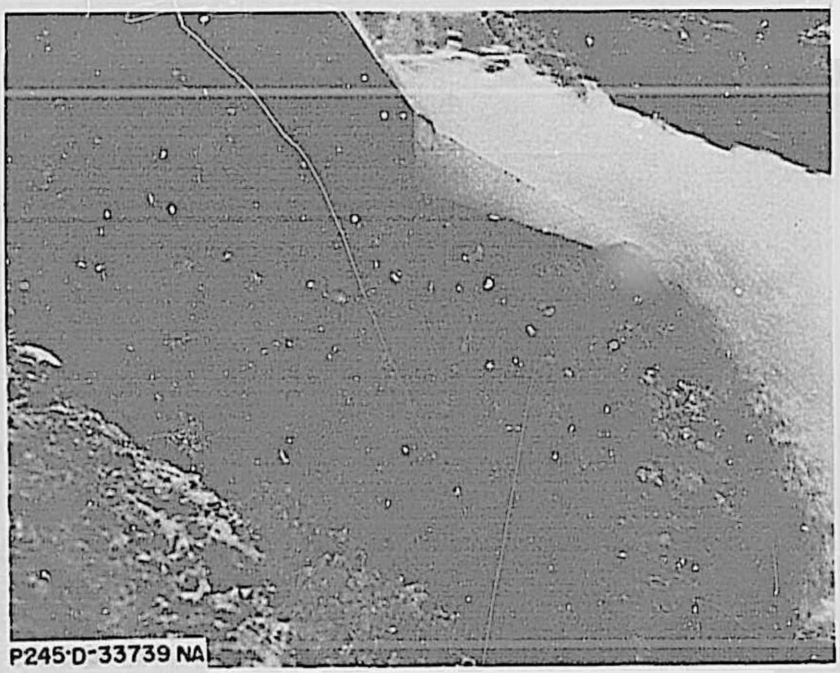
GRANBY DAM AND DIKES
LOCATION MAP

DRAWN P.M.W. SUBMITTED
TRACED W.M.S. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO, 245-D-2607

FIGURE 2
REPORT HYD-539







GRANBY DAM SPILLWAY MODIFICATION
ORIGINAL PROTOTYPE SPILLWAY DISCHARGING

FIGURE 4
REPORT HYD-539

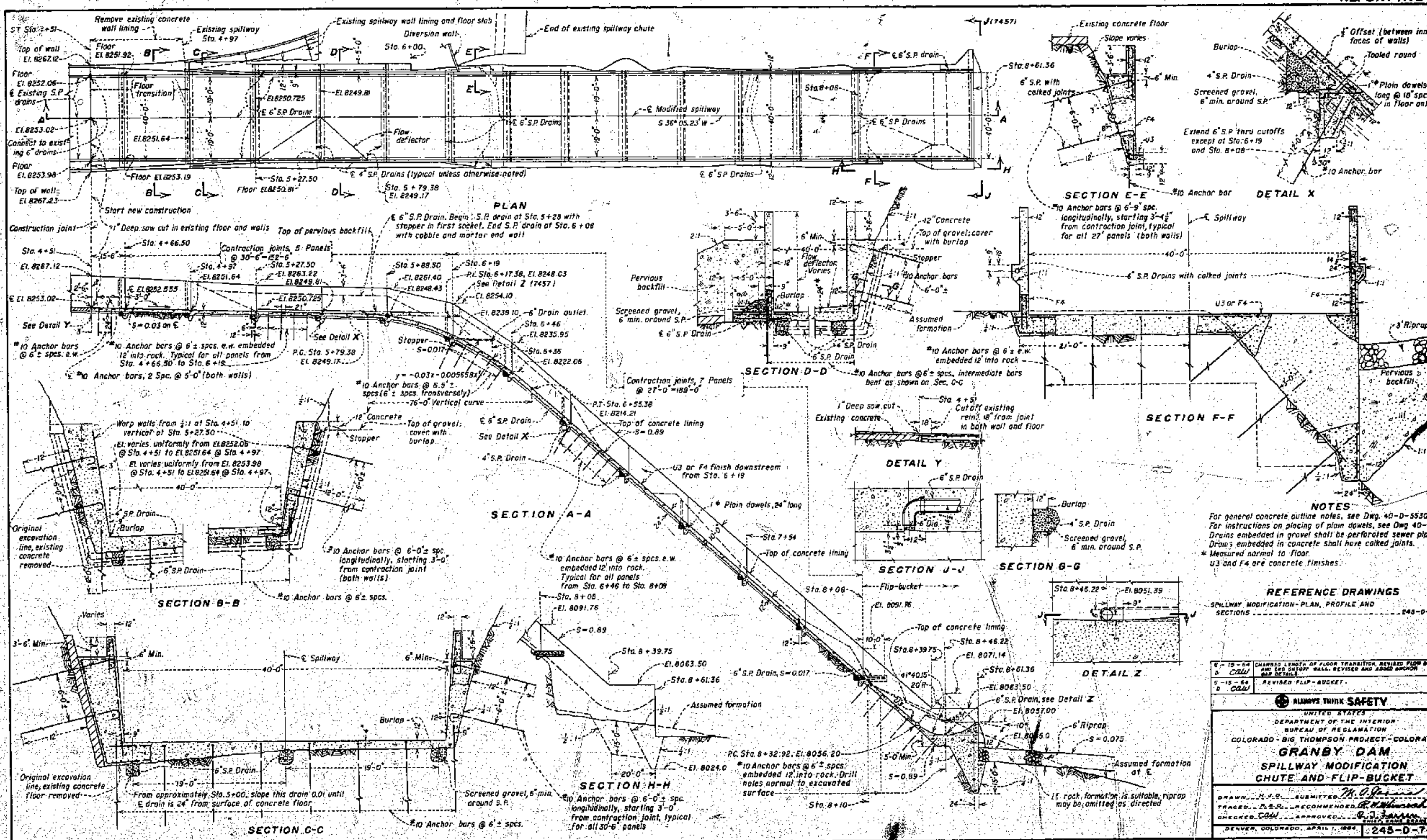


Figure 5
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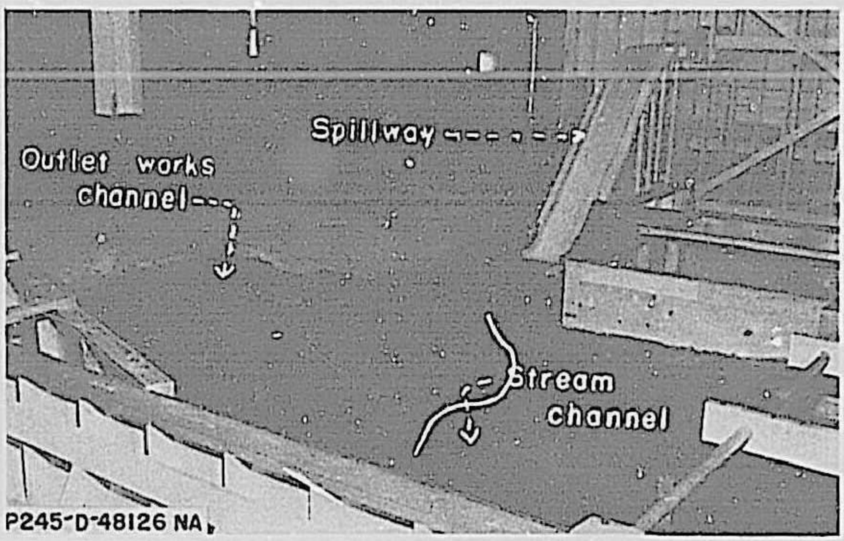
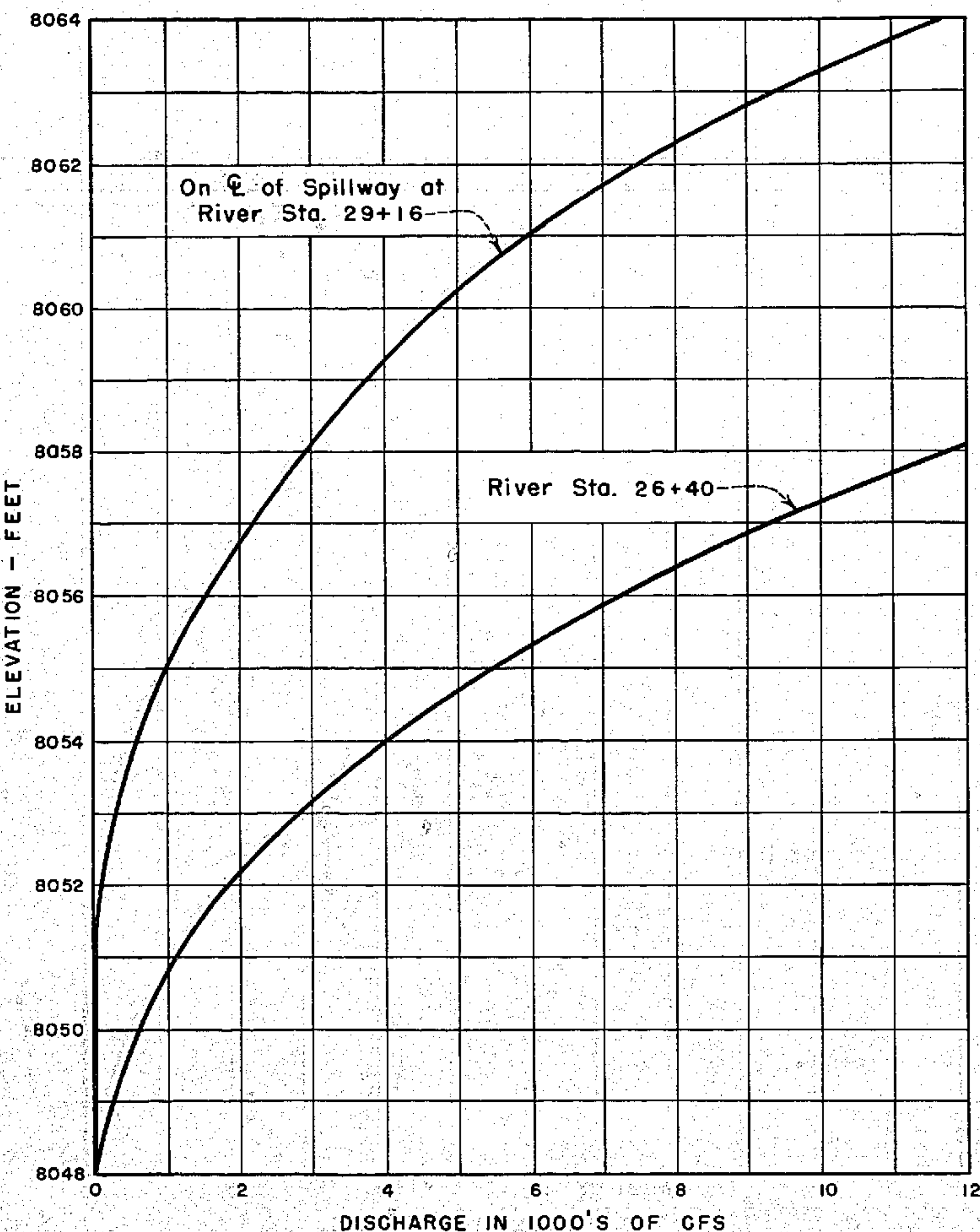
A. Spillway entrance in head box

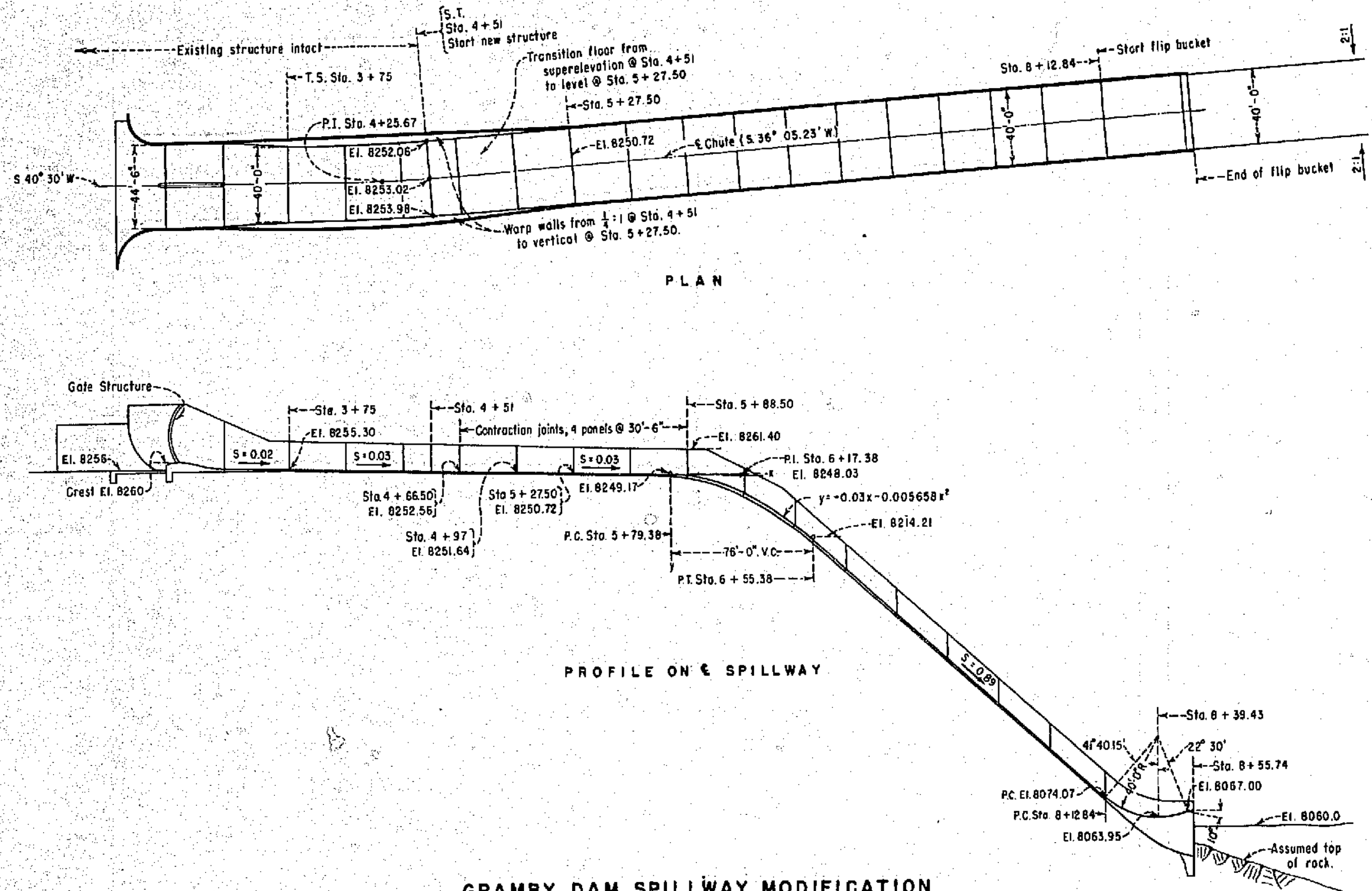


B. Spillway chute and tail box

GRANBY DAM SPILLWAY MODIFICATION
THE 1:36 SCALE MODEL

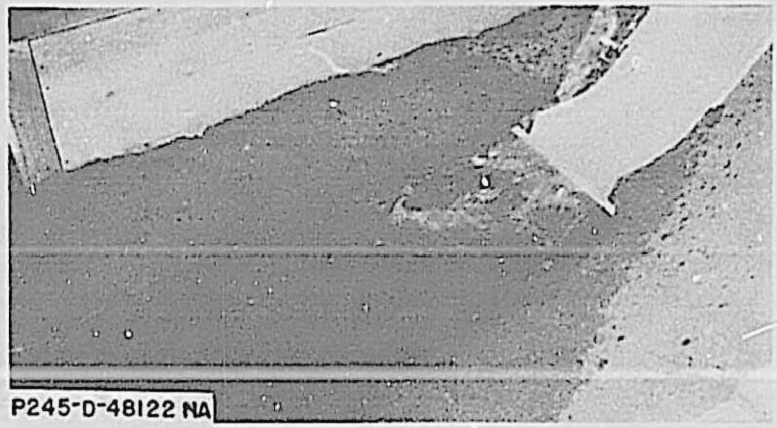


GRANBY DAM SPILLWAY MODIFICATION
TAILWATER CURVES

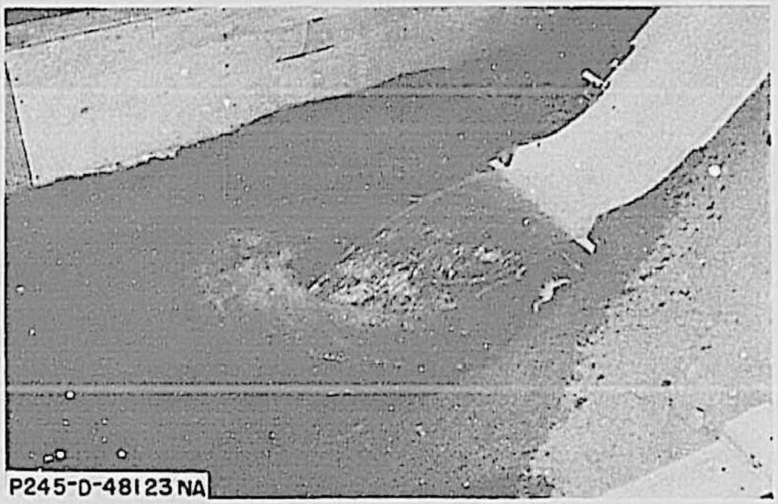


GRAMBY DAM SPILLWAY MODIFICATION
PRELIMINARY DESIGN OF CHUTE AND FLIP BUCKET

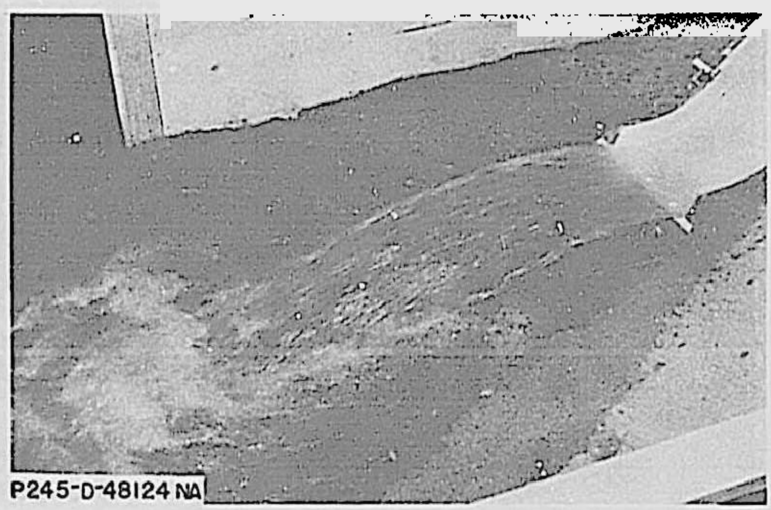
679



A. 600 cfs

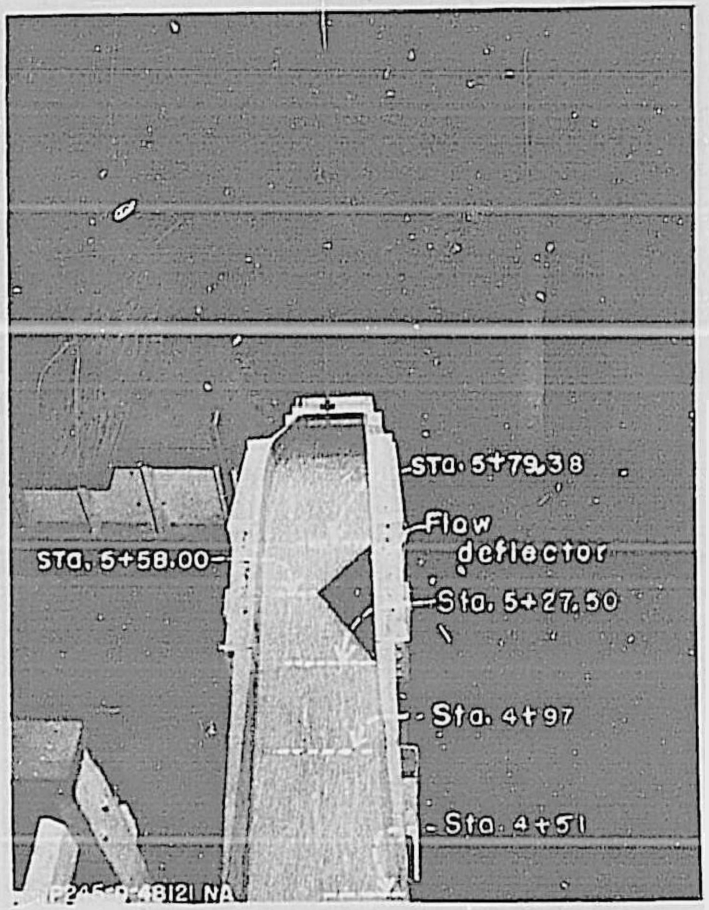


B. 1,200 cfs



C. 3,000 cfs

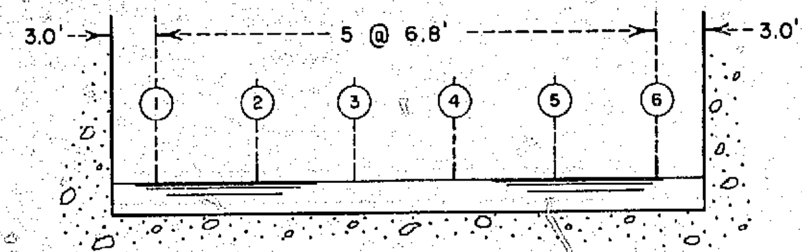
GRANBY DAM SPILLWAY MODIFICATION
FLOW FROM PRELIMINARY CHUTE AND FLIP BUCKET
1:36 SCALE MODEL



3,000 cfs

Note: The flow deflector is 1 foot high on right wall at Sta. 5+58.00.

GRANBY DAM SPILLWAY MODIFICATION
RECOMMENDED CHUTE
1:36 SCALE MODEL



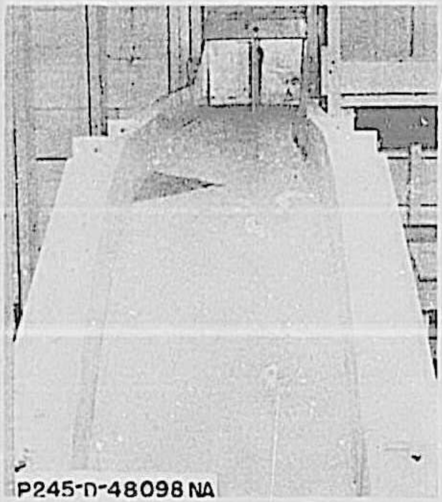
LOOKING DOWNSTREAM - STA 8 + 12.84

Note: Circled numbers designate point gage locations.

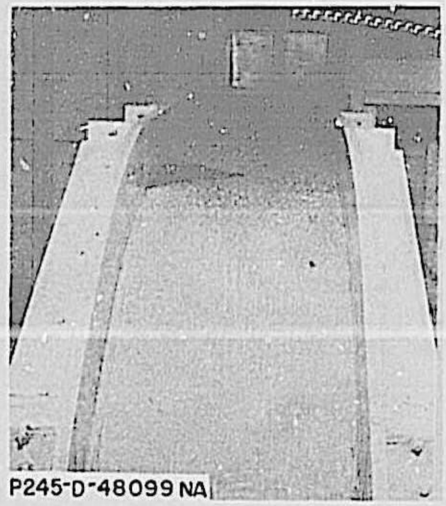
DISCHARGE CFS	GATE OPENING FT.	DEPTH OF FLOW AT POINT GAGE - FEET						AVERAGE DEPTH OF FLOW	AVERAGE VELOCITY FT./SEC.	COMPUTED VELOCITY (n = 0.013) FT./SEC.	COMPUTED VELOCITY (n = 0.008) FT./SEC.
		1	2	3	4	5	6				
600	0.5	0.21	0.32	0.32	0.29	0.36	0.32	0.31	41.0	41.5	55.55
1,200	1.0	0.46	0.58	0.54	0.47	0.58	0.44	0.52	58.5	59.5	76.72
3,000	1.5	1.12	0.97	0.90	0.94	0.90	0.97	0.97	77.2	80.5	96.15
12,000	11.0	2.38	2.59	2.77	3.28	3.35	2.70	2.84	105.5	102.9	110.2

GRANBY DAM SPILLWAY MODIFICATION
FLOW DEPTH AND VELOCITY AT STA. 8+12.84
1:36 SCALE MODEL

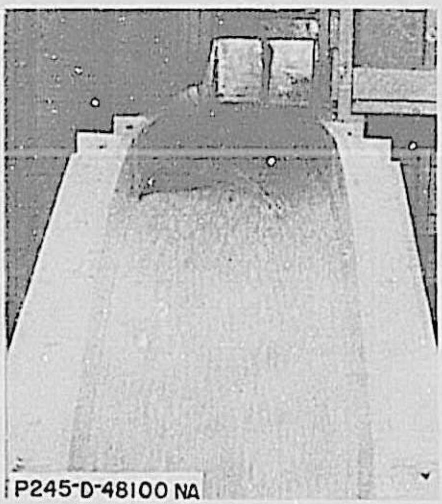
673



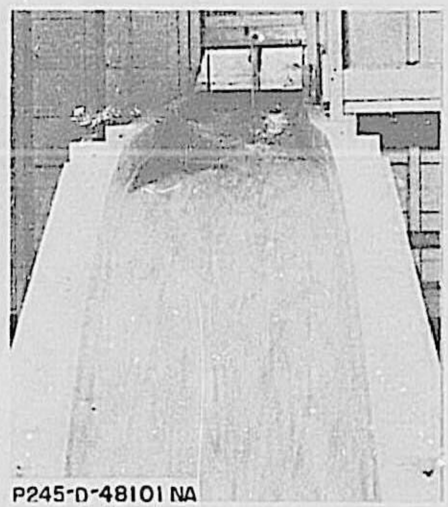
600 cfs



1,200 cfs



3,000 cfs

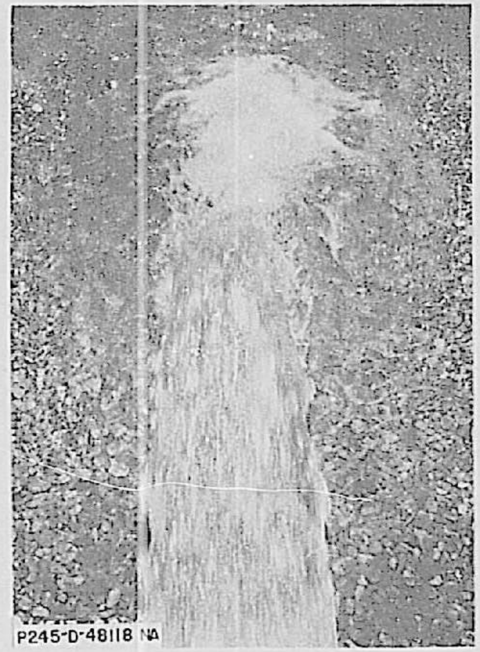


12,000 cfs

GRANBY DAM SPILLWAY MODIFICATION
FLOW IN RECOMMENDED CHUTE
1:36 SCALE MODEL

600 cfs

1,200 cfs



3,000 cfs

GRANBY DAM SPILLWAY MODIFICATION
FLOW FROM RECOMMENDED CHUTE
1:36 SCALE MODEL

Figure 13
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A. Riprap lined channel extending 150 feet downstream from bucket

B. Erosion caused by 1,200 cfs discharge

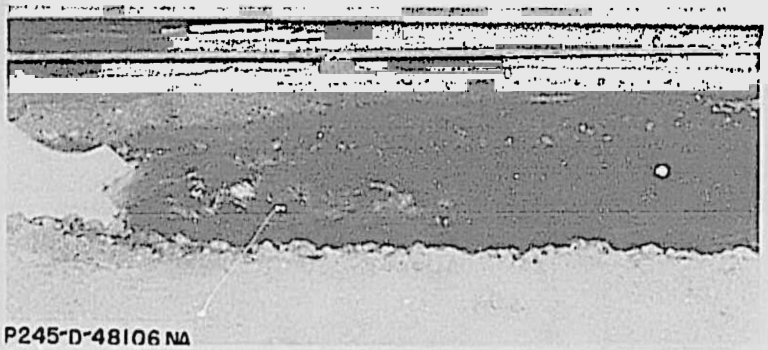
GRANBY DAM SPILLWAY MODIFICATION
EROSION IN RIPRAP LINED CHANNEL
1:36 SCALE MODEL

A. 600 cfs

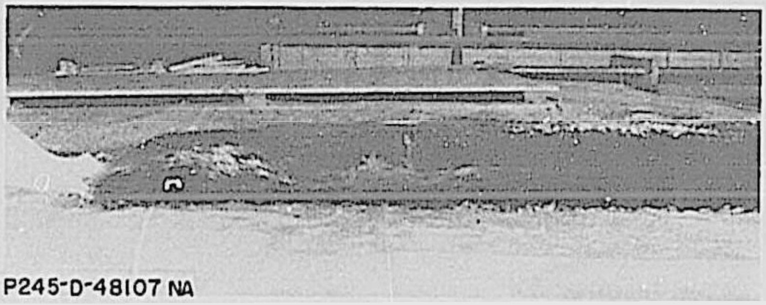
B. 1,200 cfs

C. 3,000 cfs

GRANBY DAM SPILLWAY MODIFICATION
OPERATION OF RECOMMENDED FLIP BUCKET AND PLUNGE BASIN
1:36 SCALE MODEL

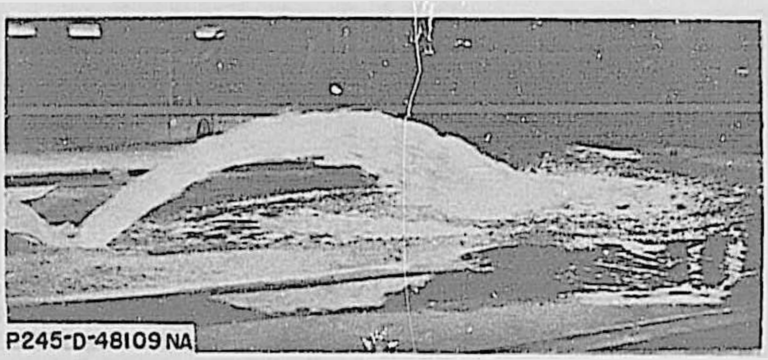


A. 600 cfs



B. 1,200 cfs

C. 3,000 cfs



D. 6,000 cfs

GRANBY DAM SPILLWAY MODIFICATION
OPERATION OF RECOMMENDED FLIP BUCKET AND PLUNGE BASIN
1:36 SCALE MODEL

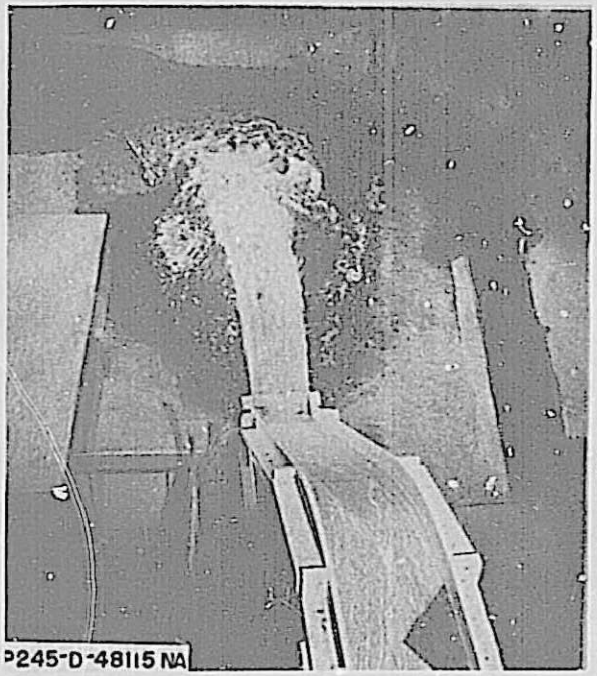
Figure 16
Report Hyd 539

A. Erosion after 3,000 cfs

B. Erosion after 12,000 cfs

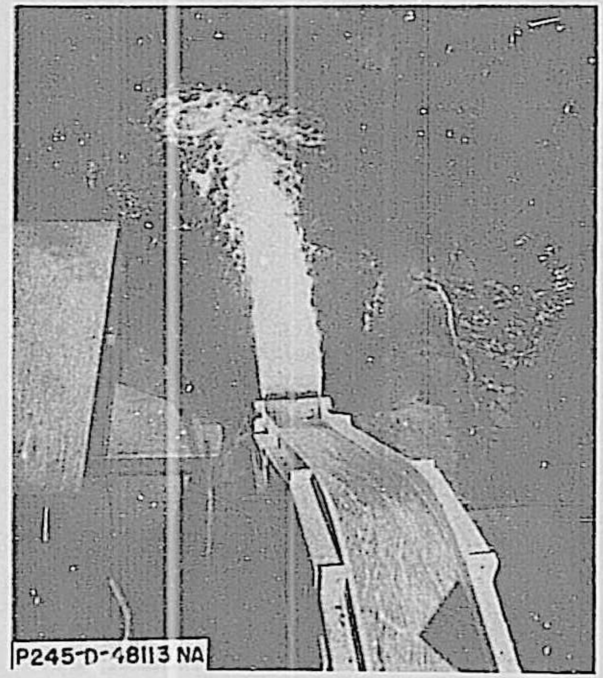
GRANBY DAM SPILLWAY MODIFICATION
EROSION IN THE RECOMMENDED PLUNGE BASIN
1:36 SCALE MODEL

Figure 17
Report Hyd 539



A. 6,000 cfs

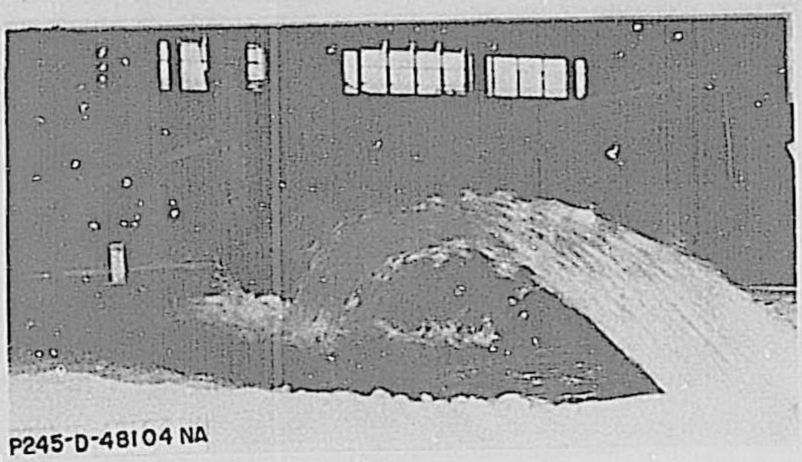
B. 9,000 cfs



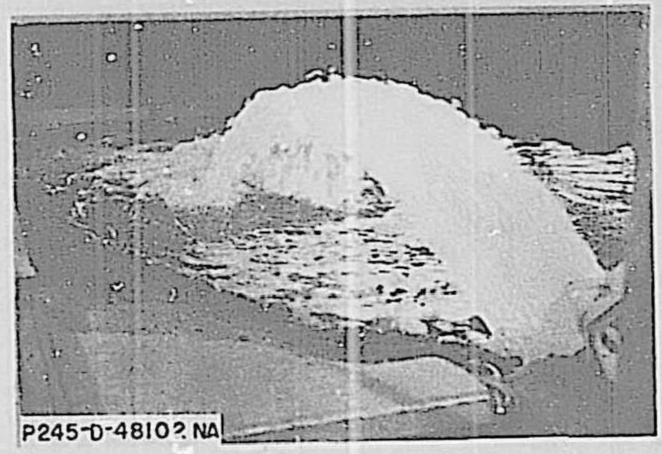
C. 12 000 cfs

Note: The dark streak across the width of the jet at the end of the bucket for flows of 9,000 and 12,000 cfs indicates interference of the pool water surface with the under nappe of the jet.

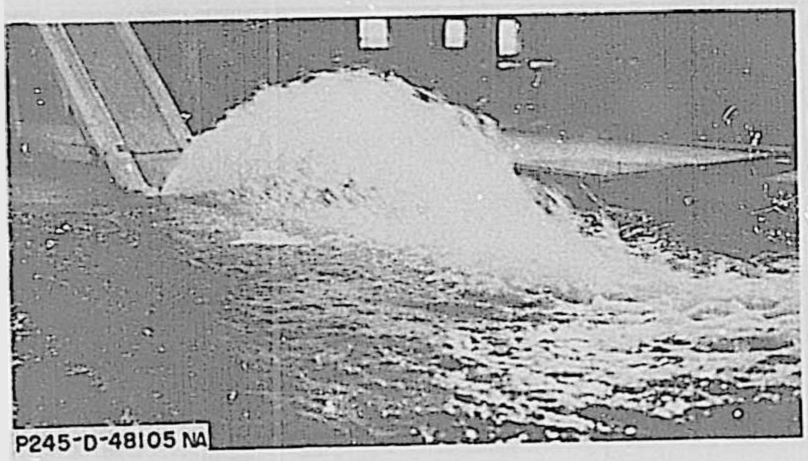
GRANBY DAM SPILLWAY MODIFICATION
OPERATION OF RECOMMENDED FLIP BUCKET AND PLUNGE BASIN
1:36 SCALE MODEL



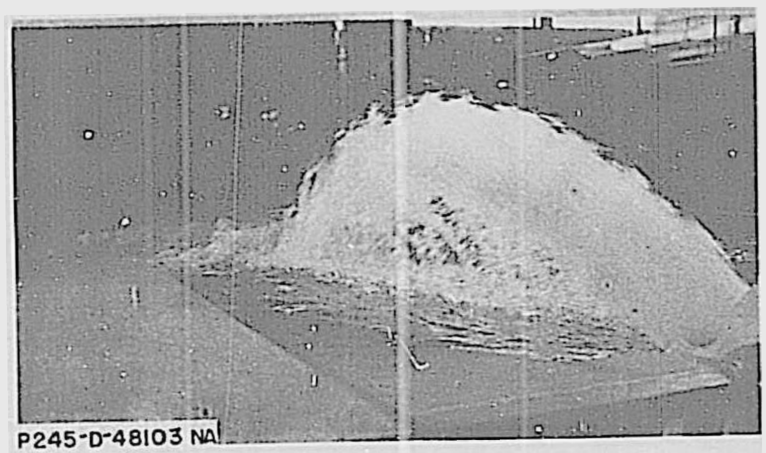
A. 3,000 cfs



B. 6,000 cfs



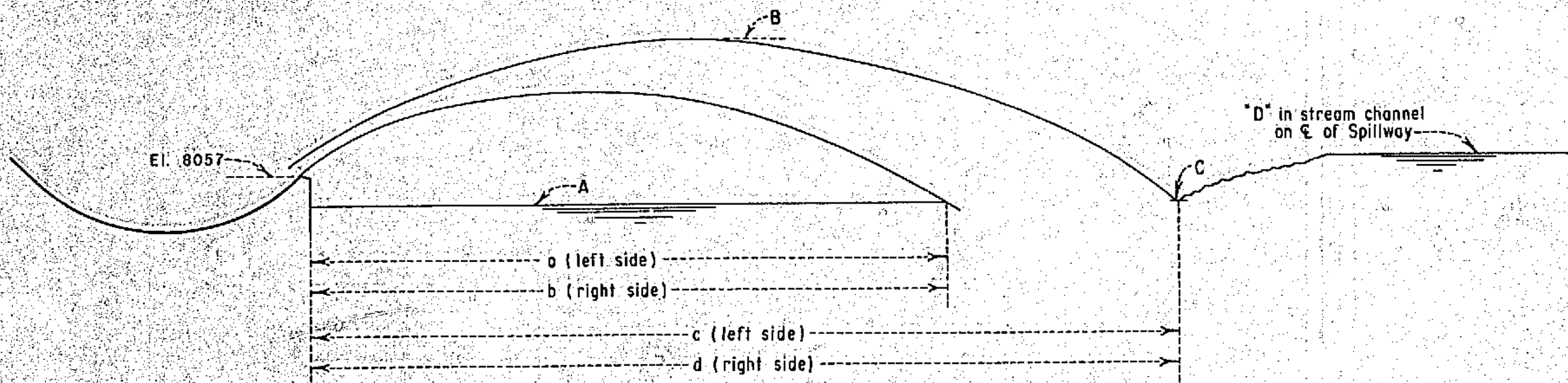
C. 9,000 cfs



D. 12,000 cfs

Note: Water surface of pool at bucket lip is interfering with under surface of the jet in C and D.

GRANBY DAM SPILLWAY MODIFICATION
OPERATION OF RECOMMENDED FLIP BUCKET AND PLUNGE BASIN
1:36 SCALE MODEL



JET DIMENSIONS AND WATER SURFACE ELEVATIONS								
DISCHARGE CFS	a	b	c	d	ELEVATION AT A	ELEVATION AT B	ELEVATION AT D	WIDTH AT C
600	0	15	30	35	8054	—	8054.5	27
1,200	40	40	75	72	8055	8073	8056	27
3,000	130	110	140	140	8054	8093	8059	18
12,000	300	300	340	340	8058	8128	8064	0

Dimensions and elevations are in feet.

GRANBY DAM SPILLWAY MODIFICATION
JET MEASUREMENTS AND WATER SURFACE ELEVATIONS
1:36 SCALE MODEL

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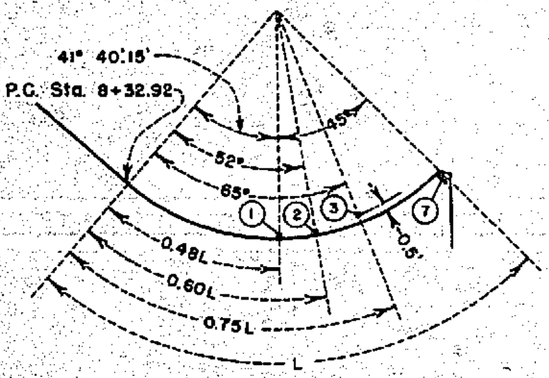
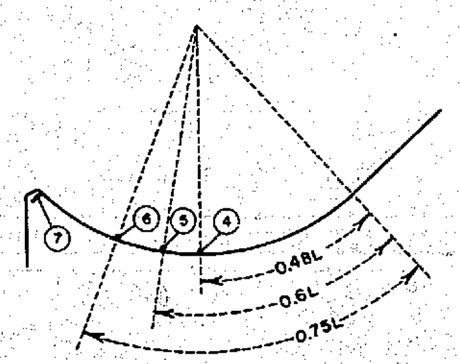
FIGURE 20
REPORT HYD-539



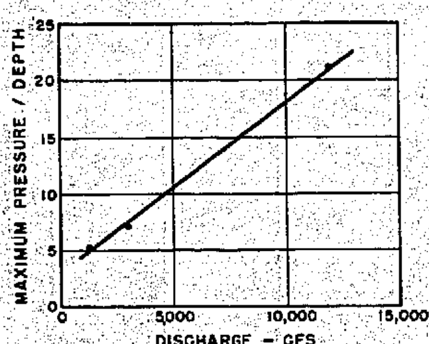
RIGHT WALL



LEFT WALL

PIEZOMETER PRESSURES								
DISCHARGE CFS	AVERAGE FLOW DEPTH AT STA. 8+12	1	2	3	4	5	6	7
1,200	0.48	1.0	-1.0	-1.0	0.0	-1.5	2.5*	—
3,000	1.01	3.5	3.5	-1.0	5.4	7.0*	5.0	-2.5
12,000	2.85	40	40	24	60*	51	53	5

Circled numbers designate piezometer locations.
Pressures and depths are in feet of water.
* Maximum pressure recorded per discharge.



GRANBY DAM SPILLWAY MODIFICATION
PRESSURES IN RECOMMENDED FLIP BUCKET
1:36 SCALE MODEL

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CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second²	0.3048*	Meters per second²
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft² deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft² deg F	1.4880*	Kg cal m/hr m² deg C
Btu/hr ft² deg F (C, thermal conductance)	0.568	Milliwatts/cm² deg C
	4.882	Kg cal/hr m² deg C
Deg F hr ft²/Btu (R, thermal resistance)	1.761	Deg C cm²/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft²/hr (thermal diffusivity)	0.2581	Cm²/sec
	0.09290*	M²/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft² (water vapor transmission)	16.7	Grams/24 hr m²
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

ABSTRACT

Hydraulic model studies of the proposed Granby Dam spillway modification indicated that the preliminary design of the modification was satisfactory with the addition of a plunge basin not originally contemplated. Operation of the existing spillway at a maximum rate of 1,168 cfs eroded the mountainside and undermined the end of the chute. The modifications proposed include removal of the downstream 160 ft of spillway and construction of a new chute with flip bucket and riprap-lined plunge basin downstream. The model studies were undertaken to develop the hydraulic design of these features. A flow deflector pad on the chute floor and a transition for the curved superelevated portion of the chute was developed to provide more nearly symmetrical flow distribution in the flip bucket jet. Increasing the tangent angle at the lip of the flip bucket to 45 deg and lowering the elevation of the basin floor at the bucket lip increased the effectiveness of the plunge basin pool. The basin was developed to still the energy in flows up to 3,000 cfs and to prevent erosion in the area adjacent to the flip bucket for flows up to 12,000 cfs. Pressures recorded in the flip bucket indicated satisfactory pressure conditions would occur at the entrance to the left wall drain and on the downstream face of the lip and that the training walls should be designed to withstand a pressure of about 60 ft of water at the invert of the bucket radius.

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Laboratory Report Hyd-539
Beichley, G. L.
HYDRAULIC MODEL STUDIES OF GRANBY DAM SPILLWAY MODIFICATION--COLORADO-BIG THOMPSON PROJECT, COLORADO
Bureau of Reclamation, Denver, 8 p, 20 fig, 1 tab, 2 ref, May 1965

DESCRIPTORS--*spillways/ *chutes/ *flip buckets/ roughness coefficients/ hydraulic models/ research and development/ model tests/ laboratory tests/ cavitation/ negative pressures/ erosion/ hydraulic similitude/ riprap/ flow control/ energy dissipation/ hydraulics/ jets/ hydraulic structures/ discharge measurement/ water pressures/ open channel flow/ erosion control/ discharges/ channels/

IDENTIFIERS--subatmospheric pressures/ Colorado-Big Thompson Project/ flow deflectors/ Colorado/ hydraulic design/ design modifications/ plunge basins

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